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For

METHODS AND APPARATUSES FOR TUNING VOLTAGE CONTROLLED OSCILLATORS

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METHODS AND APPARATUSES FOR TUNING VOLTAGE CONTROLLED OSCILLATORS

FIELD OF THE INVENTION

[0001] The present invention relates generally to digital wireless communication, and more specifically to frequency modulation using a voltage-controlled oscillator (VCO).

BACKGROUND OF THE INVENTION

[0002] The proliferation of digital wireless communication systems has led to a need for reliable modulation circuitry. Phase-locked loop (PLL) circuits are attractive in modulation applications due to their combination of controllable modulation and stable and adjustable carrier frequency.

[0003] As known in the art, a VCO can be used to effect Gaussian-shaped Continuous Phase Binary Frequency Shift Keying Modulation (GCPBFSK) in which the modulating wave shifts the output frequencies, away from the center frequency, by an amount between predetermined values. The predetermined values, i.e., two different frequencies representing zero and one, are called modulation deviation and are denoted by f_0 and f_1 respectively. The frequencies, f_0 and f_1 are typically equal. For example, for a wireless standard having 79 channels in a frequency range of 2402MHz – 2480MHz with each channel separated by 1MHz, the center frequencies may be equal to 2402MHz + nMHz (n= 0 to 78). The f_0 may range within some negative values (e.g., from –140KHz to -175Khz) and f_1 may range within a corresponding positive values (e.g. from 140KHz to 175KHz), in respect to the center frequency.

[0004] In order to keep frequencies f_0 and f_1 within their specific range, the voltage to the VCO must be controlled very carefully. Typical VCO gain (KVCO) may be on the order of 100MHz/V – 200 MHz/V. Typical VCOs may be operated from 0.6v to 2.2v,

but actually only the linear range (1.0v – 1.8v) can be used for this application, otherwise non-linear distortion will result.

[0005] For a wide frequency range (2402MHz –2480 MHz), it is difficult to maintain a linear frequency response. The oscillation frequency of a VCO circuit is inversely proportional to the square root of the product of the inductance and capacitance (LC). It is possible to divide a large frequency range into segments to obtain a piecewise linear response over each segment. This can be achieved by using a set of switch-able capacitors, varactors (whose capacitance is voltage-controllable) and inductors. Often a larger frequency range is divided to account for the tolerance values of integrated capacitors and inductors that may run as high as 30%. Each segment is then covered by a specific capacitor's combination.

[0006] The voltage-frequency characteristics of a VCO vary from chip to chip. Therefore to obtain the appropriate modulation characteristics, the voltage to the VCO must be controlled depending on the characteristics of the chip. A typical PLL circuit in accordance with the prior art includes a charge pump, which acts as a current source. The charge pump consists of a set of current sources. The appropriate current source is chosen, based on the VCO voltage-frequency characteristics, to charge the capacitors of the LPF and thus controls the voltage to the VCO.

[0007] The difficulty arises in determining the VCO capacitance value (i.e. the capacitors' combination) and charge pump current value to provide the desired modulation deviation for each channel.

SUMMARY OF THE INVENTION

[0008] A method for setting the VCO circuit capacitance value and charge pump current level is described. To set the capacitance value, the operation frequency range is divided into a plurality of frequency bands. Then the frequency of a voltage-controlled oscillator (VCO) for each combination of capacitance values and lowest / highest control voltage levels is measured. A capacitance value for each frequency band is then selected such that the frequency band is between the lowest frequency (corresponding to the lowest voltage level) and highest frequency (corresponding to the highest control voltage).

[0009] To set the charge pump current level, a representative frequency is determined for each frequency band. Then VCO gain at the representative frequency is estimated and the charge pump current level for each frequency band is selected based upon the estimated VCO gain.

[0010] Other features and advantages of the present invention will be apparent from the accompanying drawings, and from the detailed description, that follows below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The present invention is illustrated by way of example, and not limitation, by the figures of the accompanying drawings in which like references indicate similar elements and in which:

[0012] **Figure 1** illustrates a typical PLL circuit in accordance with the present invention;

[0013] **Figure 2** illustrates a VCO circuit in accordance with the present invention;

[0014] **Figure 3** is a process flow diagram in accordance with the present invention;

[0015] **Figure 4** illustrates, graphically, exemplary voltage frequency measurements in accordance with one embodiment of the present invention; and

[0016] **Figure 5** illustrates a system block diagram in accordance with one embodiment of the present invention.

DETAILED DESCRIPTION

[0017] A method and apparatus for tuning a VCO is described. An embodiment of the invention provides a method that determines the VCO variable capacitance value and the charge pump current level to provide desired modulation characteristics within a specified band.

[0018] In the following detailed description of the present invention, numerous specific details are set forth in order to provide a thorough understanding of the present invention. However, it will be apparent to one skilled in the art that the present invention may be practiced without these specific details. In some instances, well-known structures and devices are shown in block diagram form, rather than in detail, in order to avoid obscuring the present invention.

[0019] **Figure 1** illustrates a typical PLL circuit in accordance with the present invention. The PLL circuit 100, shown in Figure 1, includes a charge pump 110, fed by a current source 135. The current into the charge pump 110 determines how much current is pumped into the low pass filter (LPF) 115. This current charges the capacitors of the LPF 115 and thus controls the voltage to the VCO.

[0020] For one embodiment of the present invention the current source 135 has a number of switch-controlled current meters, not shown, that control the amount of current. Each switch may contribute current in varying amounts to provide 16 current levels. The current, which may be controlled from the CPU of a baseband chip, not shown, changes the increment/decrement of the voltage coming out of the LPF 115. The adjustable current allows varying the voltage at the voltage control layer to obtain the desired modulation. For example, the frequency of a channel may be 2402 MHz +/- 160

Khz that corresponds to V_0 +/- ΔV. The charge pump current controls the ΔV. The current switches may be set to provide the desired output. To determine the current level required the VCO characteristics must first be determined.

[0021] **Figure 2** illustrates, in greater detail, the VCO 120 of **Figure 1**. VCO 120 includes four capacitors C_0-C_3. Each capacitor has a switch D_0-D_3 that allows the capacitor to be turned on or off. The capacitors are directly controlled by the CPU of a baseband chip, not shown, that sets switches D_0-D_3. The four binary switches allow for 16 values of capacitance. The 16 values of capacitance may be chosen so that their values cover a range of frequencies much broader than the range of interest. For example, for the 16 capacitance values may cover a frequency range of 2200MHz to 2600MHz for a system utilizing a frequency range of 2402MHz to 2480MHz. This is done to account for the tolerance values of the passive components.

[0022] In order to accurately measure the VCO characteristics, the voltage source must be very well controlled. For one embodiment, voltage to the VCO 120 from the LPF 115 is cut and replaced with a control voltage from a digital-to-analog converter (DAC) 130. This is done to prevent any voltage variance from the LPF that may affect the measurement of VCO characteristics. The DAC provides voltage that is proportional to a digital input value. The DAC may thus provide voltages in uniform increments over a known linear range. For one embodiment the DAC may provide seven voltages, V_1-V_7, ranging from approximately 1.0V to approximately 1.75V in increments of approximately 0.125V.

[0023] **Figure 3** is a process flow diagram in accordance with one embodiment of the present invention. The process 300, shown in **Figure 3**, begins at operation 305 in which

the voltage/frequency characteristics of the VCO are measured for a number of capacitance value/voltage level combinations. The frequency is measured for each of the 16 capacitance values at a number of controlled voltage levels (e.g., 7 levels) provided by the DAC. The measurement may be made at another chip where a CPU and a frequency counter reside. For example, the capacitance may be set to C_0 and then a counter located on the baseband chip measures the frequency for voltages V_1-V_7. **Figure 4** illustrates, graphically, exemplary voltage frequency measurements in accordance with one embodiment of the present invention. As shown in **Figure 4**, graph 405 may indicate the measured frequencies for capacitance equal to C_0. Graph 410 and 415 may indicate the measured frequencies for capacitance equal to C_1 and C_2, respectively, continuing to C_{15} illustrated by graph 420. Of course the graphs are not continuous, but constructed from the seven discrete frequency/voltage points. For each of the 16 levels of capacitance, the frequency/voltage characteristics of the VCO will be different.

[0024] At operation 310, the results of the frequency measurements are compared to desired frequency bands, or frequencies of interest. For an embodiment in which the range of capacitor values corresponds to a frequency range greater than the range of interest, an initial determination may be made to determine a capacitance value that covers the frequency range of interest. The covered frequency range for each capacitance value is measured with two specific DAC values (e.g., V_1 corresponds to the lowest frequency and V_7 corresponds to the highest frequency). This process may be illustrated with a simple example. The frequency range of interest is denoted by $[F_x, F_y]$ where F_x / F_y is the lowest/highest frequency of the frequency band of interest. The capacitance value is chosen so that it covers the frequency range of interest, i.e. $[F_x, F_y]$.

[0025] This process is repeated for other frequency bands of interest. For example, a system using frequencies 2402MHz to 2480MHz may be partitioned into six bands each covering approximately 13MHz.

[0026] Once the appropriate capacitance value has been determined, the appropriate charge pump current may be determined by using the frequency/voltage characteristics of the VCO for the given capacitance. In a PLL circuit, the slope, S, of the VCO frequency/voltage characteristics multiplied by the current, I, should equal a constant (e.g., 14,000). Because S x I = 14,000, the slope can be used to determine the appropriate current value. The targeted constant (e.g. 14000 as shown in the above) is normally determined by the digital controlled modulation waveform, which controls the divider ratio and is not shown in the **Figure 1**.

[0027] At operation 315, a representative frequency is determined for each of the six bands. The representative frequency represents the band in terms of slope. Some wireless specifications allow for at most 10% variance in the slope, so the representative frequency must be determined accurately. For one embodiment this frequency may be obtained from the direct measurement of a number of VCO circuit chips. For one embodiment several hundred chips are tested to determine the representative frequency. The representative frequencies, determined through testing, are then applied to all chips.

[0028] At operation 320 the VCO gain (frequency-voltage slope) is estimated at the representative frequency. For one embodiment the slope is estimated through a 3rd order polynomial interpolation of selected points around the representative frequency. In an alternative embodiment the slope may be estimated through a second order interpolation.

[0029] Once the slope has been estimated the appropriate charge pump current level is determined. In one embodiment a mapping table may be used to obtain the charge pump current level corresponding to the estimated slope.

[0030] Thus, the method of one embodiment of the present invention allows an appropriate VCO capacitance level and charge pump current level to be determined for each frequency band of interest. At operation 325, the VCO capacitance value and charge pump current level is set to determined values.

[0031] The operations of determining and setting the VCO capacitance value and charge pump current level in accordance with the present invention may be implemented by hardware and/or software contained within a baseband chip. For example, the baseband chip may include a central processing unit (CPU) that can execute code or instructions stored within a machine-readable medium that may also be included within the baseband.

[0032] The machine-readable medium may include a mechanism that provides (i.e., stores and/or transmits) information in a form readable by a machine such as computer or digital processing device. For example, a machine-readable medium may include a read only memory (ROM), random access memory (RAM), magnetic disk storage media, optical storage media, flash memory devices. The code or instructions may be represented by carrier-wave signals, infrared signals, digital signals, and by other like signals.

[0033] **Figure 5** illustrates a system block diagram in accordance with one embodiment of the present invention. The system 500, shown in **Figure 5**, includes RF chip 550. RF chip 550 contains the PLL circuit having VCO circuit 520. RF chip 550 is

coupled to baseband chip 560. Baseband chip 560 includes a CPU 565 coupled to a memory device 570. Memory device 570 stores the code for the algorithm of the present invention. The CPU 565 executes the code and set registers 580 that in turn control the charge pump current level and VCO capacitance value.

[0034] In the foregoing specification, the invention has been described with reference to specific exemplary embodiments thereof. It will, however, be evident that various modifications and changes may be made thereto without departing from the broader spirit and scope of the invention as set forth in the appended claims. The specification and drawings are, accordingly, to be regarded in an illustrative sense rather than a restrictive sense.